

BLOCKING IMPEDANCE

Cross Reference to Related Applications

[0001] This application is related to and claims the benefit of U.S. Provisional Application No. 60/319,745 entitled MULTI-HOP BRIDGE FOR TRANSFERRING DATA IN A WIRELESS NETWORK filed on December 2, 2002.

Background

[0002] High-voltage underground power distribution circuits are configured in a number of different configurations. Often a single-phase underground distribution system is configured as a fused radial-circuit (see figure 1) or as a fused loop-circuit (see figure 2). The distribution circuit could also be configured in a more complex configuration consisting of branches (see figure 3). A branched circuit could take on any form.

[0003] A transient waveform is generated at the fault site on the initiation of a cable fault. This transient waveform or traveling wave, starts at the fault site and travels in both directions away from the fault. The traveling waves in either section of the circuit reflect between the fault location and a significant change of impedance in the circuit. This significant change of impedance can for example, result from the circuit open-points (end of circuit), the short-circuit caused by the fault, and by transitions from underground to overhead cables. The transition from underground to overhead presents an impedance that is sufficient to essentially block the fault signal, and therefore giving the appearance of a open-point.

[0004] A fault recorder, located at the open-point of the circuits illustrated in figure 1 and 2, would measure the traveling wave that reflects between the fault and open-point. This traveling wave reflects between the fault and open-point until its energy dissipates. If the circuits in figures 1 and 2 are fed by overhead power lines, a fault recorder in the cable section between the fuse and fault, would record the traveling waves that reflect between the fault and transition point from underground to overhead.

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[0005] When a circuit is branch as shown in figure 3, the fault signal will take different paths depending on the fault site and the branching locations. Should a fault occur on branch segment C, a fault recorder at the open end of branch segment C will record the traveling wave that reflects between the fault and open end of segment C. The fault in segment C, also generates a traveling wave that travels toward segment A. When this traveling wave reaches the intersection of segments A, B and C, the traveling wave splits and continues onto segments A and B. This split traveling wave reflects off the open end of segment B, and off a significant impedance change along segment A. The reflected wave from the open end of segment B splits at the intersection of segments A, B and C. This split traveling wave splits reflects off the fault in segment C, and off a significant change in impedance on segment A. Likewise, the traveling wave that reflects from the significant impedance change on segment A will split when it reaches the intersection of segments A, B and C, and continue onto segments B and C. The traveling wave created by the fault in segment C seen on segments A and B is therefore a combination of multiple reflections off the fault and significant impedance changes in segments A and B. A fault recorder at the open end of segment B would therefore record a complex wave shape that consists of multiple reflections.

[0006] Should a fault occur in segment B of the branched circuit shown in figure 3, a fault recorder located at the open end of segment B would record the traveling wave that reflects between the fault and open end of segment B. Likewise, a fault recorder located at the open end of segment C would record a combination of reflections from the fault and significant changes in impedance on segments A and C. This process would be similar to that described in the previous paragraph.

[0007] The fault in segment C would create a simple traveling wave that reflects between the fault and open end of segment C. A fault recorder at the open end of segment C could effectively capture the traveling wave that is isolated between the fault and open end of segment C, and use the traveling wave to estimate the fault location. Similarly, a fault recorder at the end of segment B could effectively capture a simple traveling wave generated from a fault on segment B, and use traveling wave to estimate the fault location. A complexity occurs when the fault is in section A.

[0008] A fault in section A would cause the fault recorders at the open ends of section B and C, to record complex waveforms resulting from multiple reflections. Since a branched circuit could take any form, multiple solutions for the fault location estimation would result. This limits the usefulness of a fault recorder and estimator for branched circuits.

Summary of the Invention

[0009] The purpose of this invention is to effectively utilize a fault recorder to estimate fault location on a branched circuit or circuit lacking a significant change in impedance at a desirable location. When a circuit is branched or lacks a significant change in impedance, an impedance can be introduced into the circuit. The purpose of the added impedance is to control the path taken by the traveling waves used for fault location estimation. This added impedance is essentially a blocking impedance whose purpose is to present a sufficient impedance on non-faulted connected lines so as to effectively block a majority of the fault signals from entering non-faulted connected cable sections.

[0010] Further, this invention describes a method of controlling the path taken by the traveling wave that results from a cable fault on a power distribution circuit. By controlling the path taken by the traveling wave, a more cost effective and deterministic means of fault estimation can be achieved. This method allows for a blocking impedance to be installed at any desired locations within a circuit. The blocking impedance provides a reflection point for the traveling waves. Further, this allows a fault recorder to be installed at any desired location to record traveling waves over controllable cable sections.

Brief Description of the Drawings

[0011] Figure 1 (Prior Art) is a schematic diagram of a radial circuit for underground power distribution.

[0012] Figure 2 (Prior Art) is a schematic diagram of a loop circuit for underground power distribution.

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[0013] Figure 3 (Prior Art) is a schematic diagram of a branch circuit for underground power distribution.

[0014] Figures 4 and 7 are schematic diagrams of a branch circuit that includes an embodiment of the present invention.

[0015] Figure 5 is a schematic diagram of a radial circuit that includes an embodiment of the present invention.

[0016] Figure 6 is a schematic diagram of a loop circuit that includes an embodiment of the present invention.

[0017] Figure 8 is a perspective view of a ferrite impedance device.

[0018] Figure 9 is a graph of impedance versus frequency which is useful for describing the impedance devices used with the subject invention.

[0019] Figure 10 is a schematic diagram illustrating a configuration of a blocking impedance according to the present invention.

Detailed Description

[0020] If the circuits of figure 1 and 2 are fed from underground rather than overhead, there is no reflection point for the traveling waves at the fuse or feed point. Significant impedance however can be readily introduced into the circuit at the feed point to create a point of reflection for the traveling waves. This impedance can be created using components such as a resistor, inductor or ferrite. The impedance should be sufficient to cause a majority of the traveling wave to reflect back toward the fault location.

[0021] The blocking impedance can be achieved using a resistor, inductor, ferrite or similar passive device in the neutral line at the desired location. A resistor is not a practical solution in terms of size and cost, when designed for a power distribution system. An inductor could be used, but would need to be designed to handle normal circuit conditions as well as fault conditions. Under fault conditions the inductor would be subjected to

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currents many times higher than that of normal circuit operations. The resulting coil capable of operating under all circuit conditions would be quite significant. Although the coil could be relatively inexpensive, it would require significant testing. Further, it would require changes to grounding practices that could be objectionable to some electric utilities. A benefit of the coil is that it could be designed so that the impedance it presents remains essentially constant over the applied current range. Both the resistor and inductor would be installed in series with the neutral line. A ferrite would be installed around the neutral line, removing the need to open the line for installation. Since the ferrite is not installed in series with the neutral and it does not carry current, and its design requirements are significantly reduced. Further, use of a ferrite would not affect grounding practices. Conversely, a ferrite saturates at high currents typical of that produced by cable faults. The ferrite implementation therefore has limitations that are overcome by using a coil. The resulting impedance provided by the coil and ferrite are frequency dependent. Therefore, the coil and ferrite are specifically designed to block traveling wave of specific bandwidths.

[0022] Figure 4 illustrates a blocking impedance using a coil on the simple branched circuit. A coil is series connected in the neutral line of the branch segment B, at the intersection of segments A, B and C. With this configuration, the circuit appears to consist of two independent circuits, when viewed by fault recorders at the open ends of segments B and C. Segment B appears as a single circuit. A fault recorder at the open end of segment B would record the simple traveling wave caused by a fault on segment B, that reflects between the fault and open end. Similarly, a fault recorder at the open end of segment C would record the simple traveling wave caused by a fault on segment A or C. The blocking coil on segment B imposes an impedance to the traveling wave on segments A and C, thereby effectively isolating segment B. This prevents multiple reflections from connected non-faulted cable segments. When a fault recorder sees multiple reflections from connected segments, it becomes difficult to estimate the fault location. By effectively isolating cable segments using a blocking impedance, a very effective and deterministic means of fault location estimation can be applied to branched circuits.

[0023] Likewise, a blocking impedance using a coil could be installed at the fused or feed end of a circuit. This would effectively create a simulated open point for traveling wave reflections. This would be particularly useful in situations where it is desirable to

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locate a fault recorder at the fused or feed end of the circuit. This would create a reflection point where one may not otherwise exist. This method could also be used to segment an otherwise excessively long cable into more definable lengths to facilitate fault location estimation. There are limitations on the effective cable length that fault estimators can function. By effectively segmenting a cable using blocking impedances, one can extend the usefulness of a fault location estimator. Figure 5 illustrates a blocking impedance installed at the feed or fused end of a cable circuit, and Figure 6 illustrates a method for segmenting a long cable into measurable segments to facilitate fault location estimation. Note also in Figure 6 that an optional two-channel fault recorder could monitor segments on either side of the pseudo open-point created by the blocking installed blocking impedance.

[0024] Figure 7 illustrates a branched circuit with a ferrite blocking impedance installed on the neutral line of cable segment B, at the intersection of segments A, B and C. The ferrite creates an effective blocking impedance to traveling waves on cable segments A and C. Therefore, a fault recorder at the open end of segment C, would record a simple traveling wave that reflects from a fault on segments A or C and the open end of segment C. This blocking impedance blocks multiple reflections from connected non-fault branched cable sections, enabling an effective and deterministic method of fault location estimation on branched circuits. When a fault occurs on cable segment B, the ferrite blocking impedance will often saturate and lose its blocking impedance properties. If a fault recorder is located at the open end of segment B, a fault on segment B that causes the ferrite to saturate will not affect the traveling wave that reflects between the fault and open end of segment B.

[0025] It should be noted that the branched circuits illustrated on the included drawings consist of a single branch for simplicity and clarity of the explanation. A branched circuit can consist of many branches and take any form. A blocking impedance can be installed at any of the branch locations to control the path taken by a traveling wave, and further provide a reliable means of fault location estimations. The fault recording and location estimating can be readily achieved using the Fault Distance Monitor (FDM) product commercially available by Remote Monitoring Systems, Inc. The use of a blocking impedance extends the usefulness of products like the Fault Distance Monitor.

[0026] Figure 8 illustrates a ferrite installation using a two-piece iron powder based ferrite blocking impedance typical of what would be used for the disclosed implementation. Both the inductor and ferrite blocking impedance desirably present an impedance to the traveling wave to significantly block a majority of the traveling wave. This use of a ferrite or inductor to filter or block high frequency signals on conductors is a well understood practice and not repeated here. The traveling wave to be blocking under this disclosure is fairly broad band in nature, and has a majority of its energy in the 10KHz to 1MHz range. Further, a typical underground distribution cable has a characteristic impedance of about 30 Ohms. A blocking impedance of 300 to 600 Ohm within the 10KHz to 1MHz is sufficient enough to effectively block a majority of the traveling wave. Figure 9 illustrates the desired impedance characteristic of the blocking impedance.

[0027] The following are equations for the voltage and current reflection coefficients, with a calculation using the peak blocking impedance and the characteristic impedance of the cable. The cable impedance is actually a complex impedance that depends on the complex propagation velocity. The blocking impedance too is a complex impedance, having a characteristic as illustrated in Figure 9.

$$P_v = (Z_b - Z_c) / (Z_b + Z_c) = -P_i$$

$$P_v = (600 - 30) / (600 + 30) = 0.905 \text{ (90\% of the incident wave is reflected)}$$

P_v – Voltage Reflection Coefficient

P_i – Current Reflection Coefficient

Z_b – Load Impedance Presented by Installed Blocking Impedance

Z_c – Cable Characteristic Impedance

[0028] The above discussion has centered around a practical application of this invention based on interfacing with existing power distribution circuits and circuit components. Emphasis was placed on adding the blocking impedance to the neutral line only because of ease of access to this line at junction or branching points. A cables' center

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conductor or hot line is often terminated with an elbow or other similar commercial terminator, leaving limited access. Further, a hot line component must be designed for all conditions experienced by the cable circuit, including faulted conditions where current levels can reach many times that of normal operation. There are commercially available terminating impedance devices called reactors that can be tuned to match a desired frequency response. A reactor is large and expensive, but has the added benefit of arc suppression which limits the fault current. Use of reactors is typically limited to power substations.

[0029] The concentric neutral line is more readily accessible than the hot line. The neutral is often striped of insulation, mechanically connected to the neutral of the joining cables, and connected to earth ground. A blocking impedance can be readily installed in a neutral line prior to its connection to earth ground. Figure 10 illustrates the physical connections using a coil or inductor on a branched cable. The elbows are connected together using standard bushings.

[0030] Much this discussion surrounds underground power distribution circuits. This method can also be effectively applied to overhead power distributions circuits to facilitate cable fault location estimation.